

From Earth (GCM) to Exoplanet (GCM)

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and

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(GSFC)

Astrobiology?

Astrobiology is the study of the origin, evolution, distribution, and future of life in the universe: extraterrestrial life and life on Earth. **This interdisciplinary field encompasses the search for habitable environments in our Solar System and habitable planets outside our Solar System**, the search for evidence of prebiotic chemistry, laboratory and field research into the origins and early evolution of life on Earth, and studies of the potential for life to adapt to challenges on Earth and in outer space.

Motivations at GISS?

- 1.) Find the water: A major goal in the Astronomical community is to find planets around nearby stars that are likely to support liquid water on their surfaces.
- 2.) Future project will target such candidate habitable worlds for transmission spectroscopy and imaging.
- 3.) Our 3-D Planetary GCM (ROCKE3D/GREP) will be able to verify the ability of a given planet to host liquid water and its distribution over the surface.

Origins of our local group

- 1.) Two previous NAI attempts with AMNH, Columbia, Lamont-Doherty
- 2.) Radial Velocity & Kepler observations of Extrasolar Planets
- 3.) In house planetary expertise: Cassini results from Titan (Tony) & Mars observations and research (M. Allison et al.)

Funding

- 1.) SIF FY 2012-2013: GREP (Generalized Rocky ExoPlanet) GCM
- 2.) STG FY 2013-2014: Planetary Climate from Earth to Exoplanets
- 3.) Del Genio: PATM 2014: Titan-Earth Early-Earth Comparisons with the GREP General Circulation Model
- 4.) Sohl: Exobiology 2014: Reconstructions of a Snowball Earth: A Data/Model Perspective
- 5.) NAI 2014-2019: Rocky Planet Habitability: Insights from Solar System Climate Dynamics Through Time

Work to-date

- 1.) Paleo Earth: snowball earth glaciation (Linda/Mark/Jeff)
- 2.) Different Stellar Spectra: M-Star Spectrum (OBAFGKM)
[FYS in the future]
- 3.) Modern day Mars (then Paleo Mars...)
- 4.) Inner Edge of the Habitable Zone

	likeMars [1]	Earth S0X	likeNeoproterozoic	likePhanerozoic	like M star GJ876
EXTERNAL PARAMETERS					
Radius (km)	3383	6371	6371	6371	6371
Gravity (m/s ²)	3.711	9.80665	9.80665	9.80665	9.80665
Day (sec)	86400	86400	86400	86400	86400
Insolation	Sun at 1.52366 AU	Sun at 1 AU (1367 W/m ²) for		Sun at 1 AU (1367	GJ876 spectrum but
Rotation period (hr)	24.623	23.934426	23.934426	23.934426	23.934426
Revolution period (d)	686.91	365	365	365	365
Eccentricity	0.093	0.017	0.017	0.017	0.017
Obliquity (deg.)	25.19	23.44	23.44	23.44	23.44
Longitude of periapsis (deg.)	280.3	282.9	282.9	282.9	282.9
psf Surface pressure (mb)	6.37391	984	984	984	984
p _{top}	0.3 [2]	150			?
Mass of Air (mair)	44.01 (CO ₂)	28.9655 (Earth)			28.9655 (Earth)
Composition (thermodynamic)	100% CO ₂	Earth	Earth		Earth
Composition (radiative)	Earth N2-O2-Ar	ppm CO ₂ [1850-2003]	Earth N2-O2-Ar		Earth
Aerosols	None	As in AR5 NINT	As in AR5 NINT		As in AR5 NINT
Topography	Mars	As in AR5 NINT	50m uniform elevation		As in AR5 NINT
Surface	Desert	off	Desert; Ent off		on - yes, Matthews
Water reservoir	vapor concentration	As in AR5 NINT	As in AR5 NINT		As in AR5 NINT
MODEL PHYSICS					
Resolution	4x5x20L	4x5x20L	ocean, 40L		Prescribed 1850 SST
Model top		0.1 mb	0.1 mb		0.1 mb
Moist convection	limiter fix (as in master	entrainment limiter fix	entrainment limiter fix		AR5 NINT
Clouds	AR5 NINT?	AR5 NINT?	AR5 NINT?		AR5 NINT
Boundary layer	ATURB	ATURB	ATURB		ATURB_E1
Topography	Mars Olympus Mons=13k	Earth	50m elevation		Earth
Land-ocean distribution	Current Mars	Earth	reconstruction A (old)		Earth
Ocean type	None	65m Qflux	Coupled		Prescribed
Land ice	condensation now active;	Earth as in AR5 (i.e.,			Earth
NOTES on other relevant	tables extrapolated from	Planck function	Shortened LOD (21.9		
Footnote [1]	Many of the Mars	Footnote [2]	CO2X amounts		

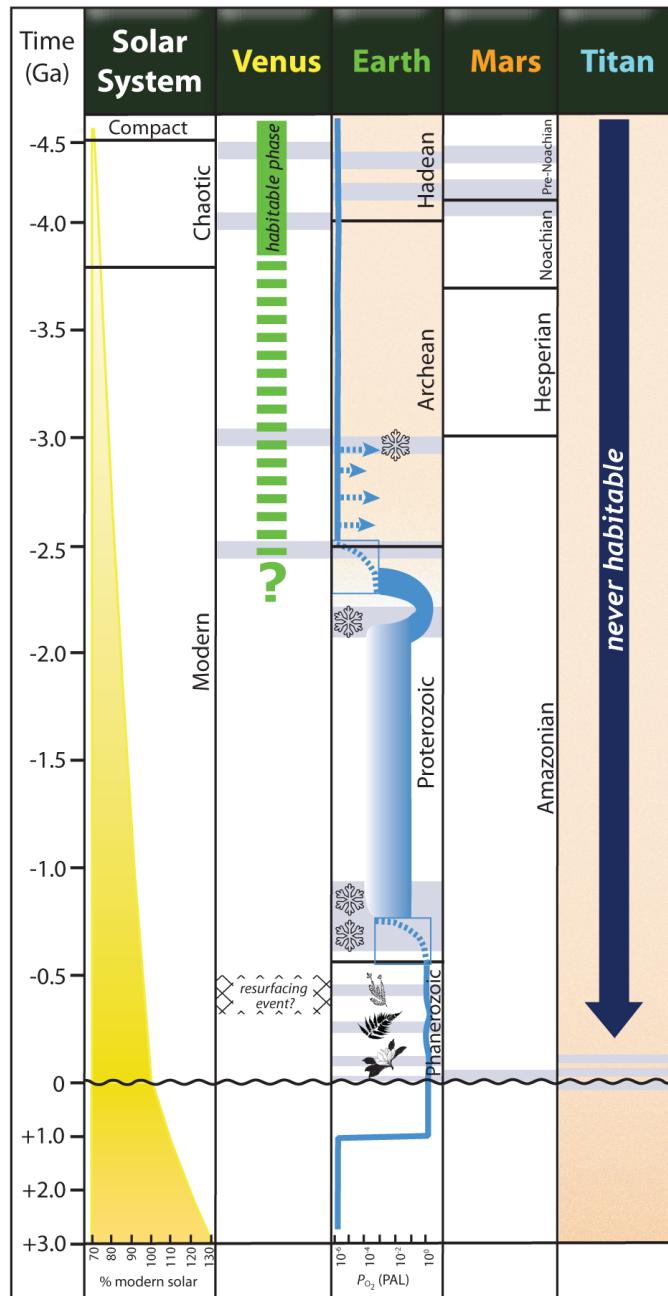
Footnote [1]	Many of the Mars parameters mentioned above can be set in model/shared/PlanetParams_mod.F90	Footnote [2]	reached when p _{topo} =0.1 is required OR the marstopo_cap13K.nc topography file is used (cuts max height of Olympus Mons to 13,000m).
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Paleo-Earth

Linda Sohl, Mark Chandler, Jeff Jonas

General context of Paleo-Earth experiments

- Hadean (4.6 - 4.0 Ga)
- Archean (4.0 - 2.5 Ga)
- Proterozoic (2.5 - 0.54 Ga)
 - “Snowball Earth”
 - Ediacaran
- Phanerozoic (0.54 - 0 Ga)
 - Ordovician
 - Triassic/Jurassic
 - Cretaceous



Paleo-Earth Time Periods

Proterozoic Eon

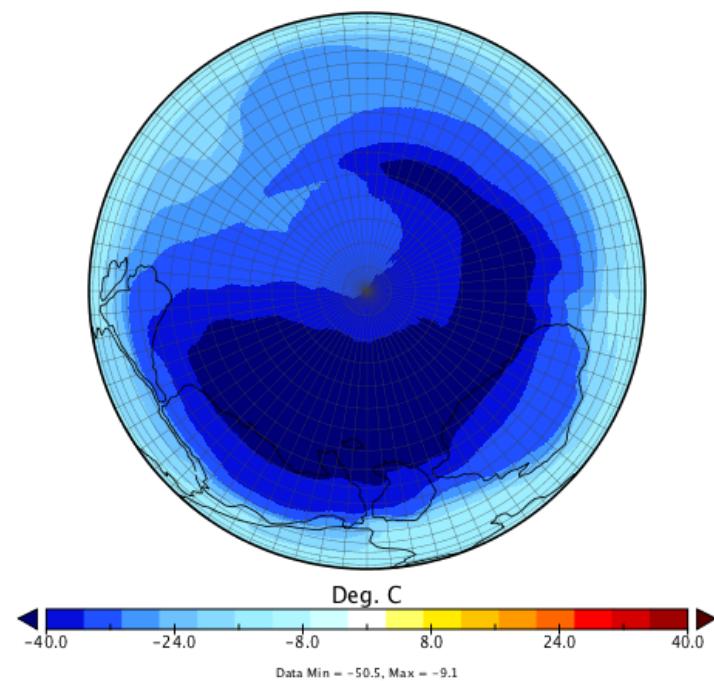
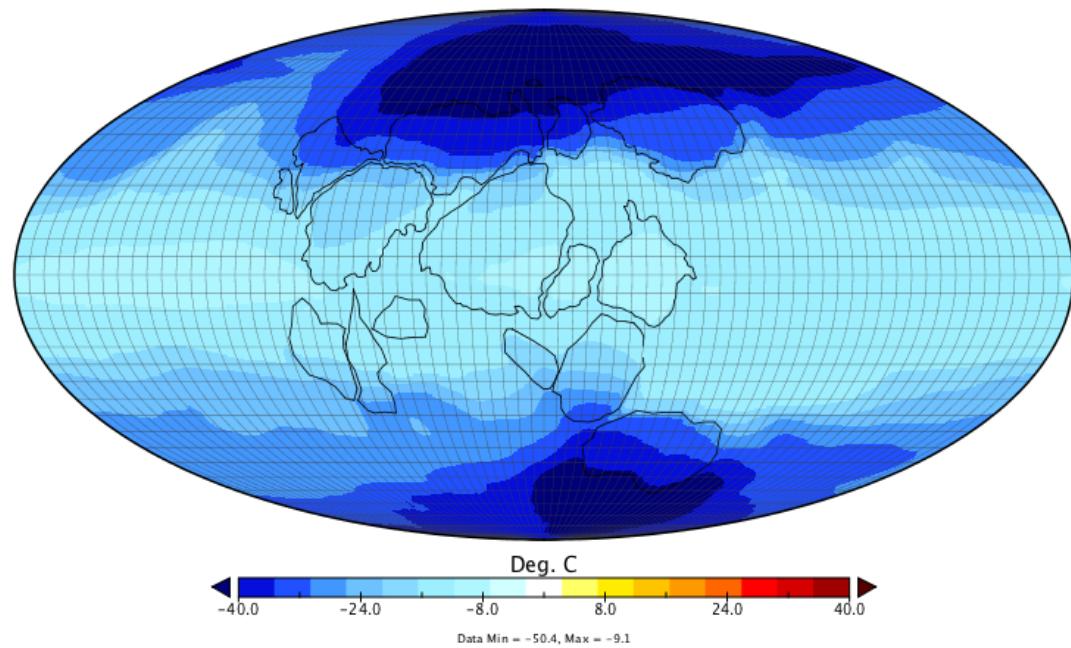
- Snowball Earth (750-635 Ma) – major glaciations – sea ice to the equator?
- Ediacaran Period (ca. 560 Ma) – first appearance of macroscopic multicellular organisms

Phanerozoic Eon

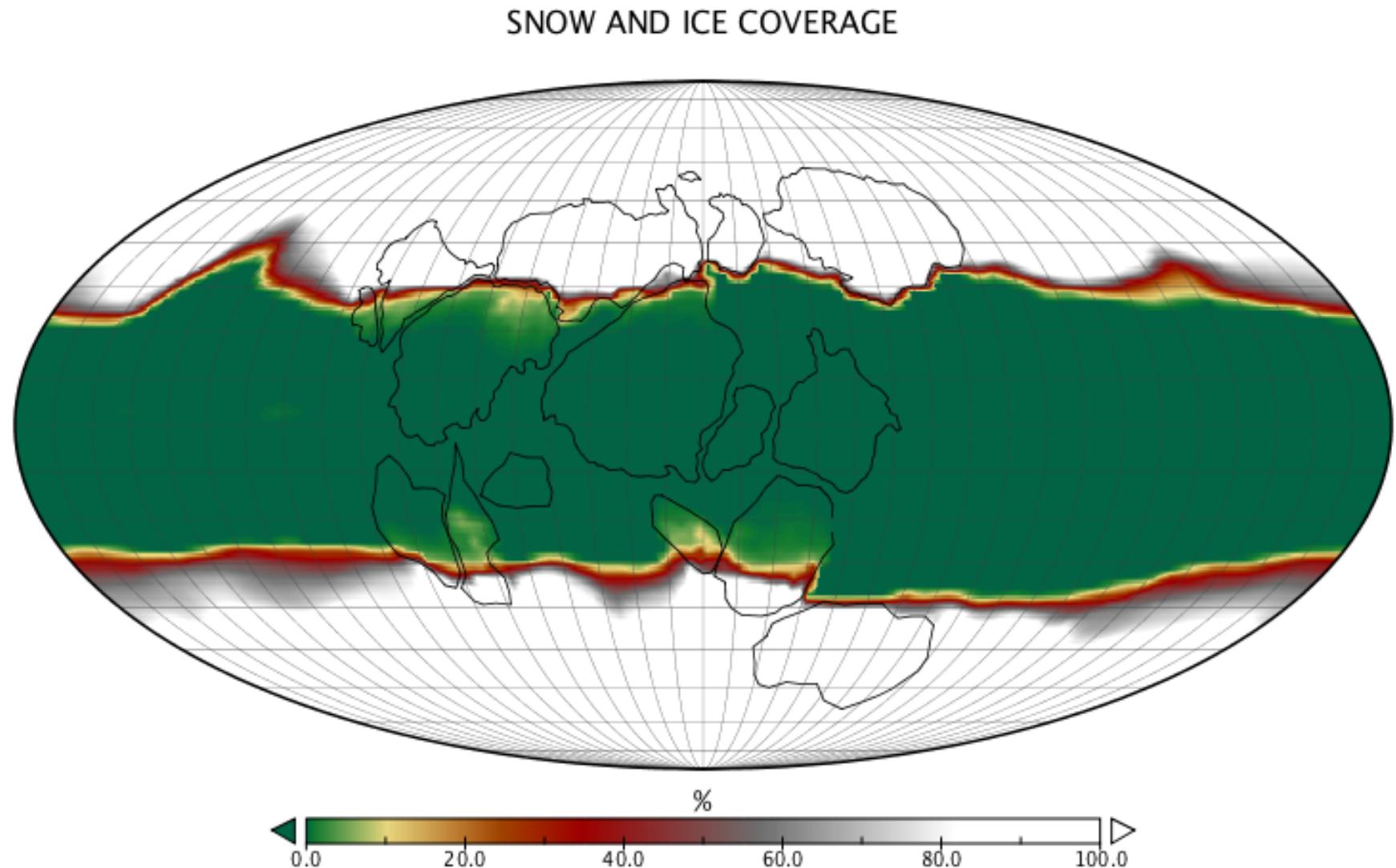
- Late Ordovician Period (465-444 Ma) – just before land colonization by plants
- Triassic/Jurassic boundary (ca. 201 Ma) – supercontinent, desert/vegetation mix
- Cretaceous Period (145-66 Ma) – no ice, lush vegetation to high latitudes – superhabitable?

Preliminary Snowball Earth Results

Surface Air Temperature Anomaly



Preliminary Snowball Earth Results



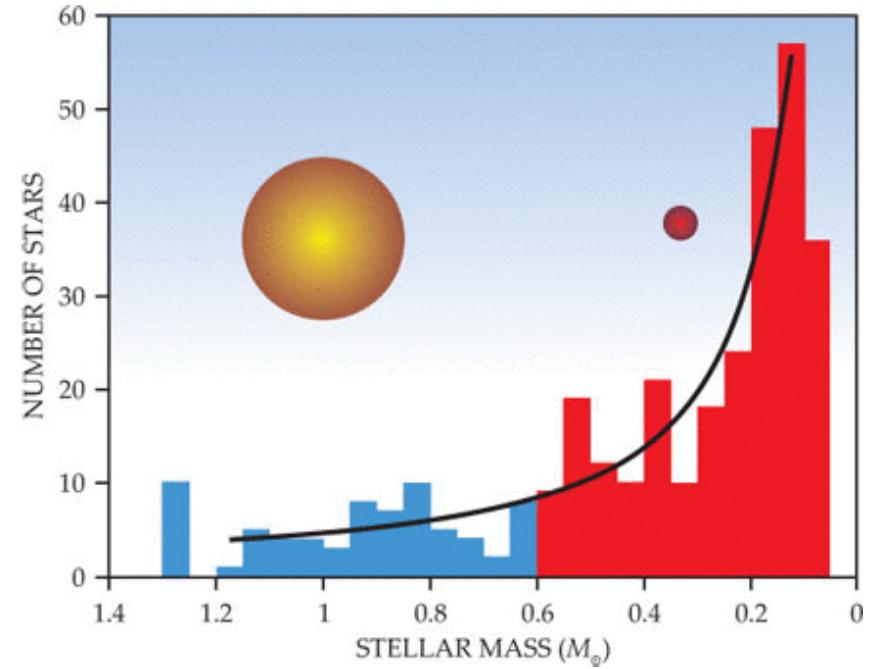
Inputting different Stellar Spectra

M-star

Nancy Kiang

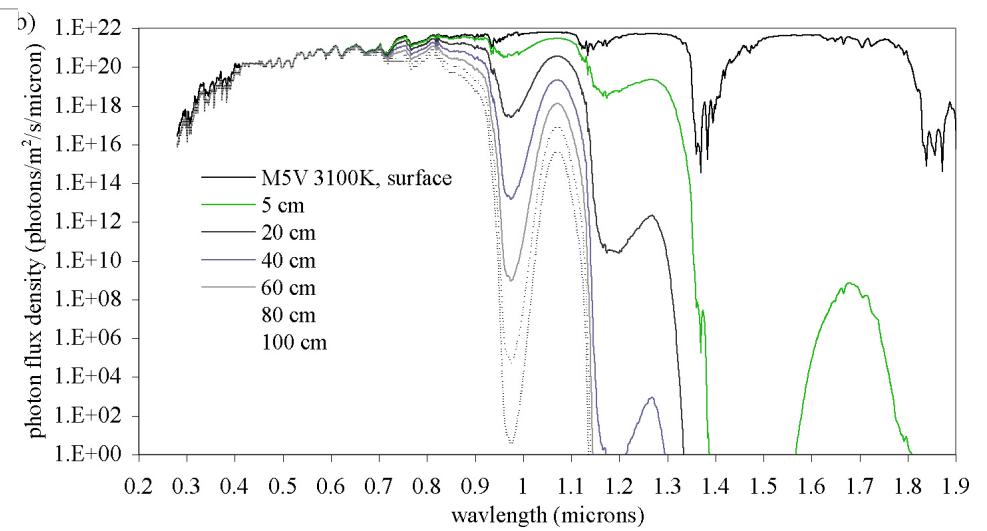
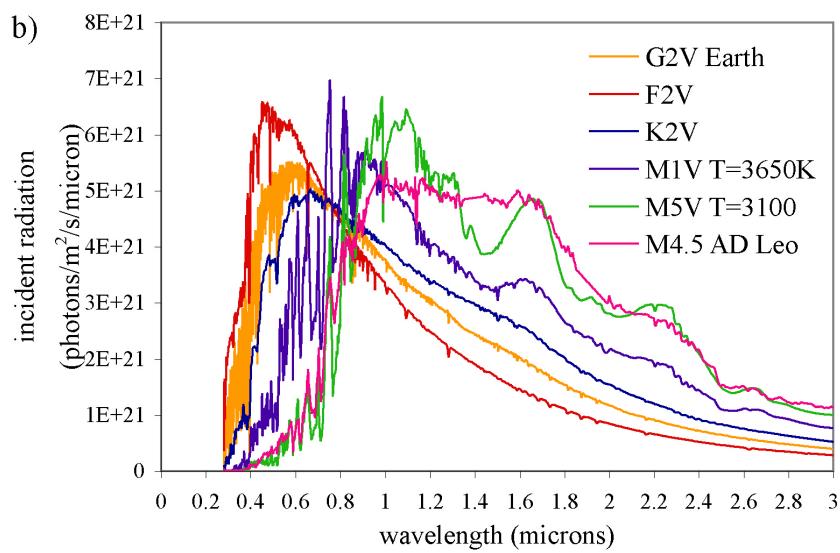
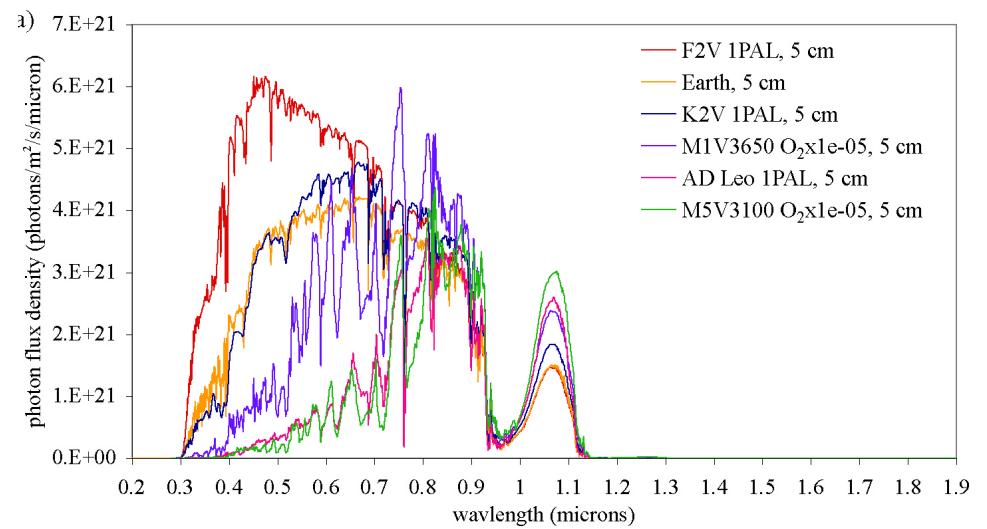
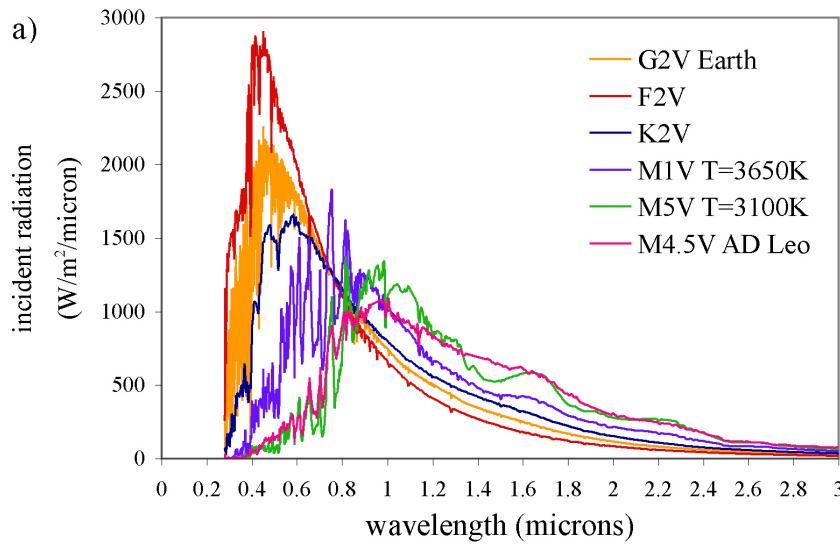
Red Dwarf M Star Stellar Spectra

- Cool, long-lived stars ~ 100 's Gyr
- UV flares when young
- Very low UV when mature
- Low VIS
- Higher NIR
- Habitable zone ~ 0.1 AU
- Planet can be tidally locked

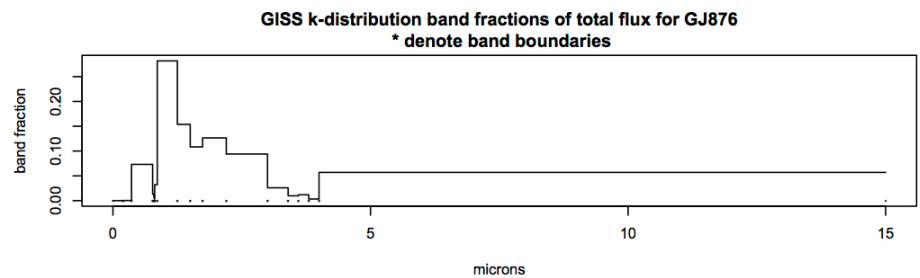
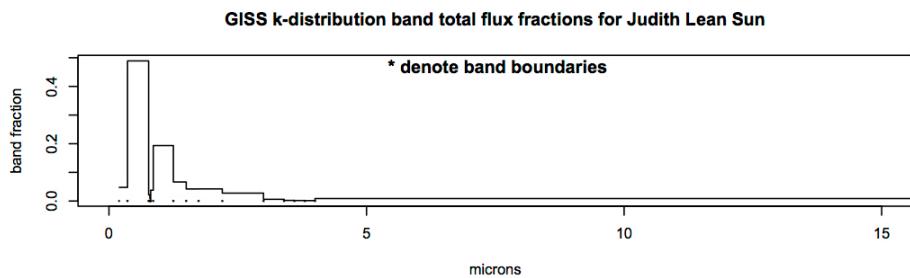
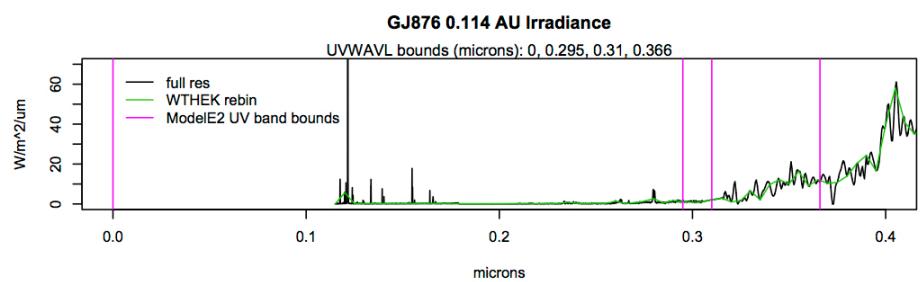
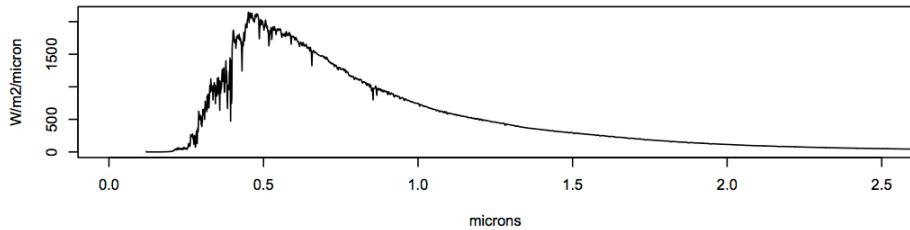
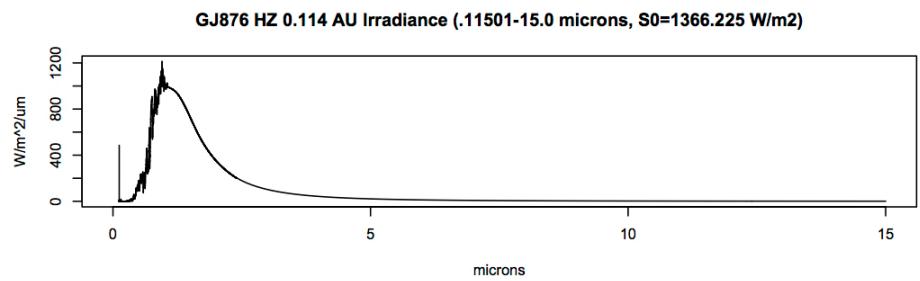
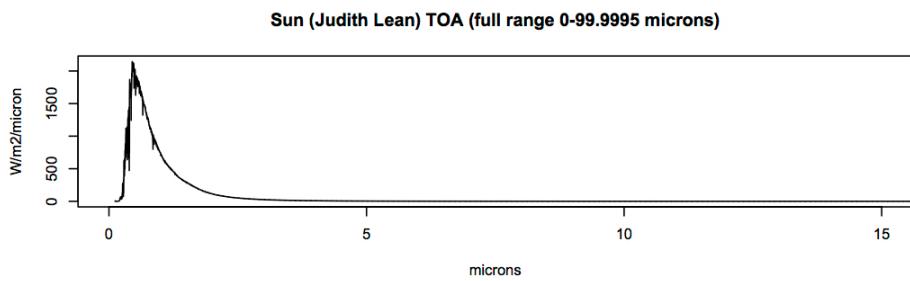


The mass distribution of all stars within 30 light-years of the Sun is plotted in units of the Sun's mass M_{\odot} .

M-Star vs G-Star

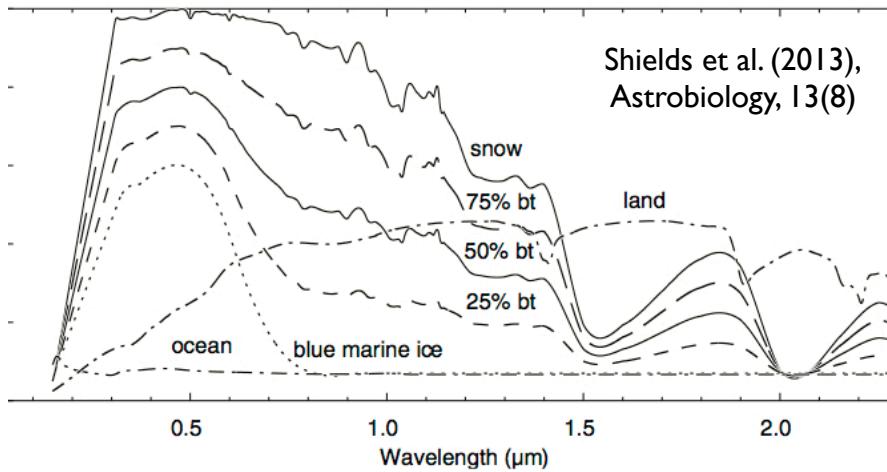


M-Star vs G-Star

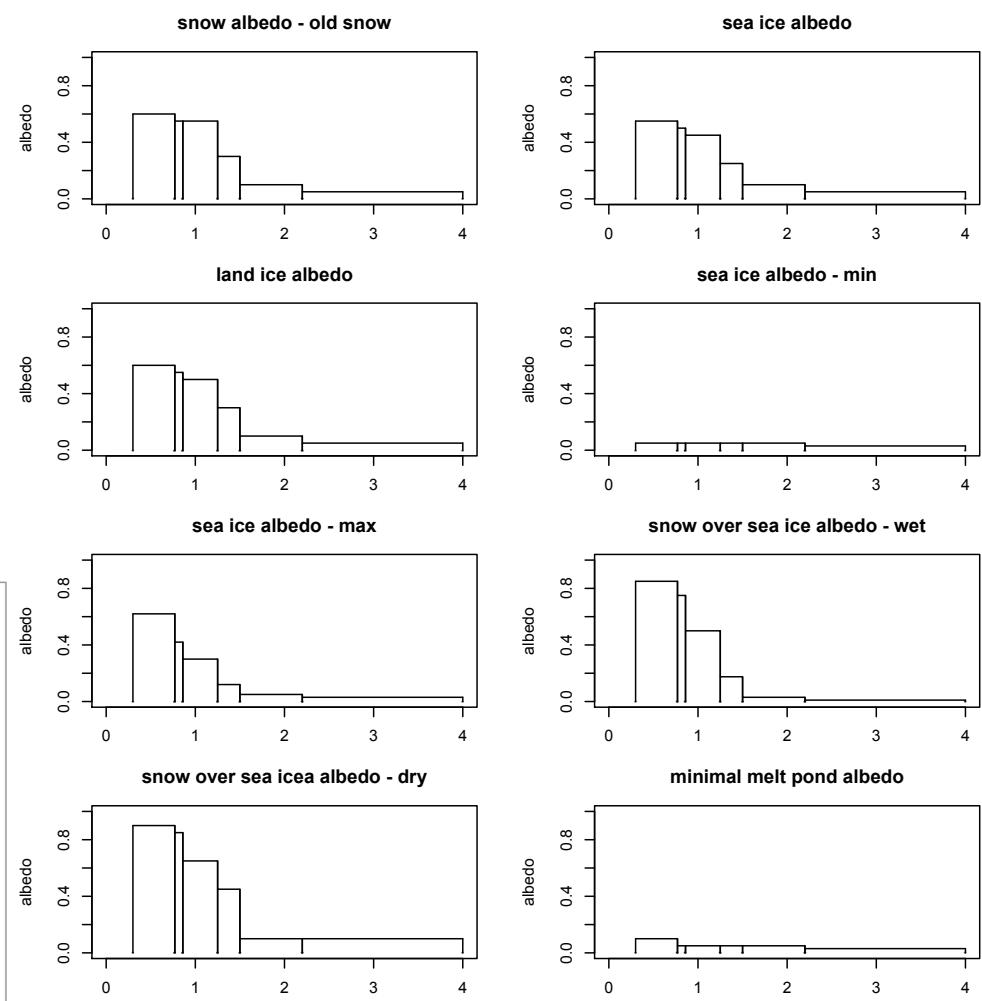


Water absorbance, snow and ice spectral albedo

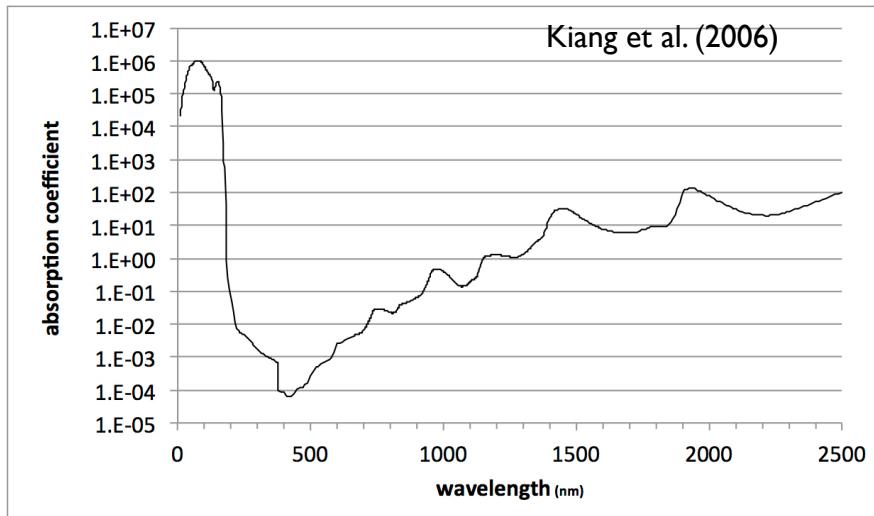
Misc ocean, ice, snow, land



GISS GCM snow and ice



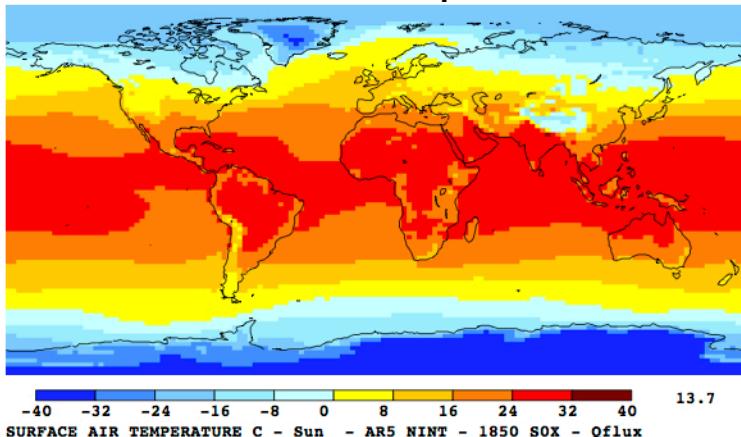
Water spectral absorbance



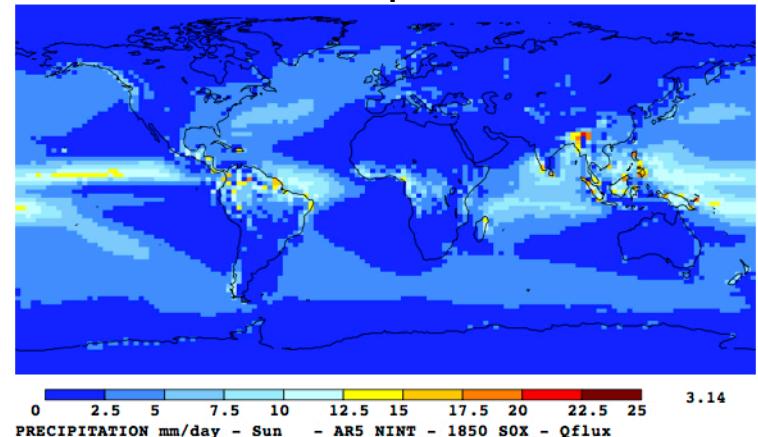
ModelE Run:

- AR5 NINT, 1850 SOX, Qflux
- GJ876 stellar spectrum

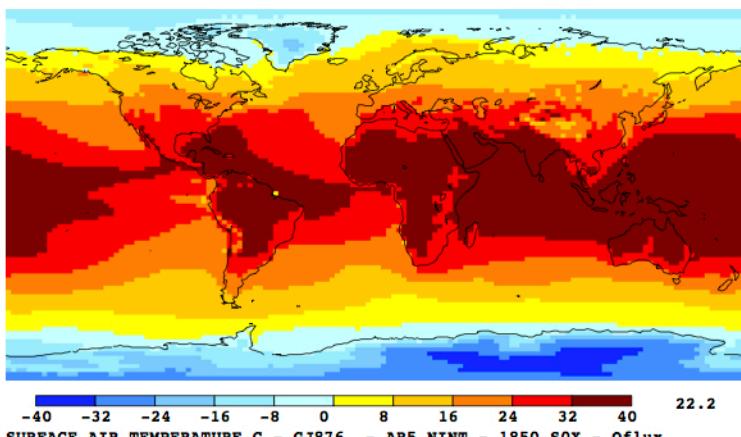
Surface temperature



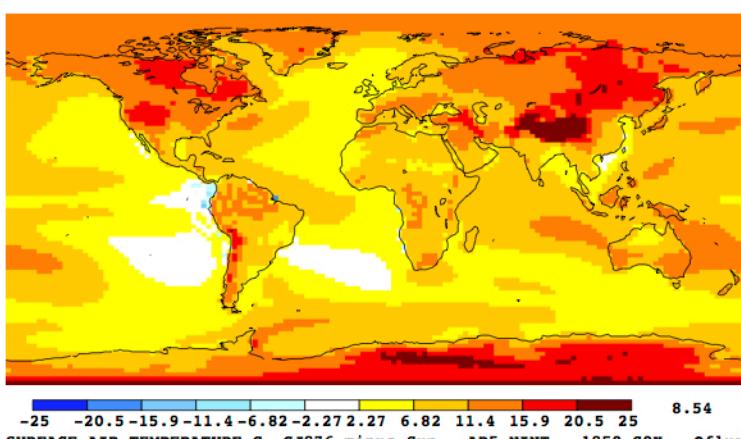
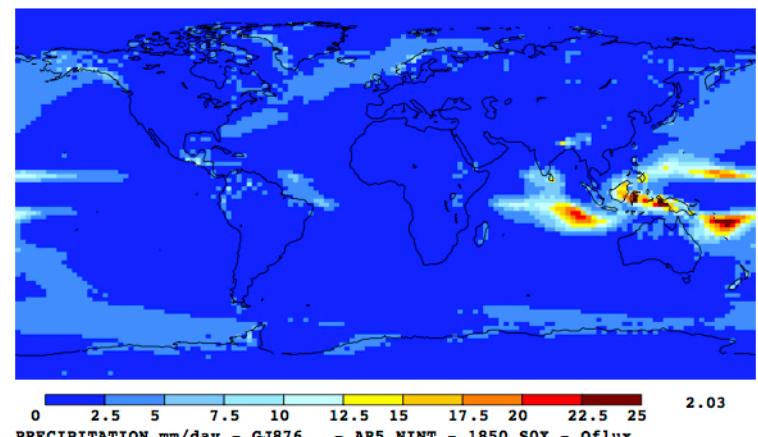
Precipitation



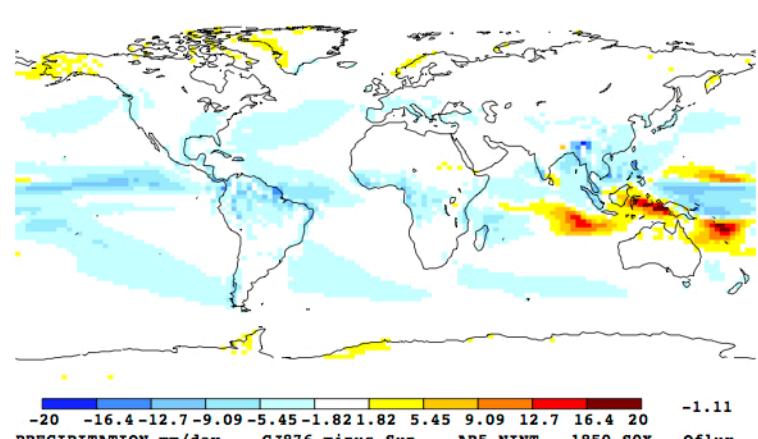
Sun



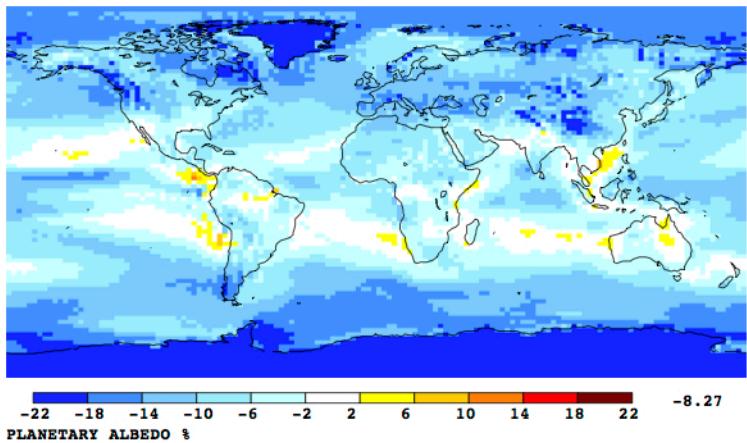
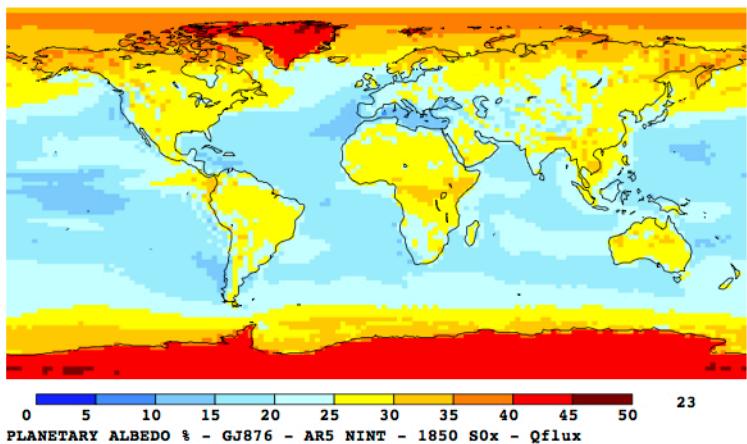
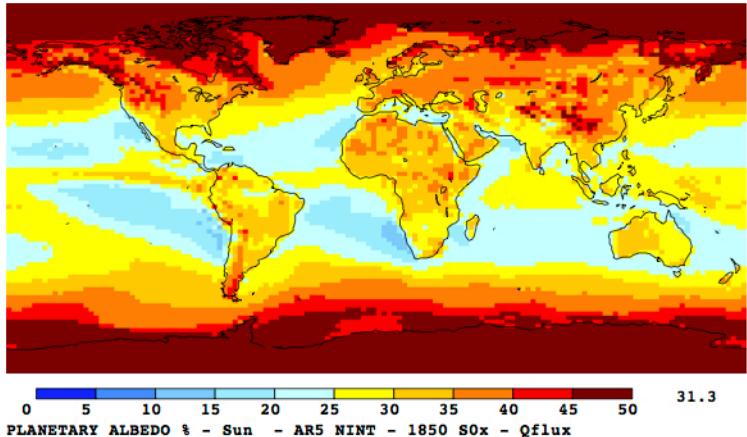
GJ876



GJ876
minus
Sun



Planetary Albedo

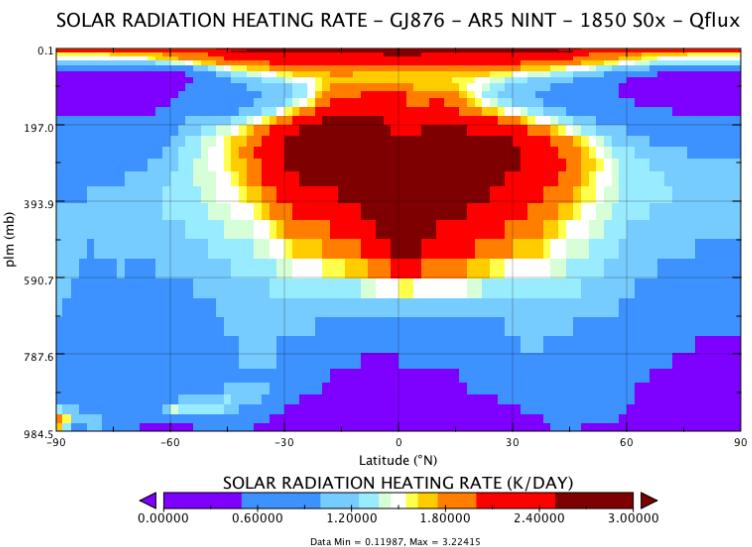
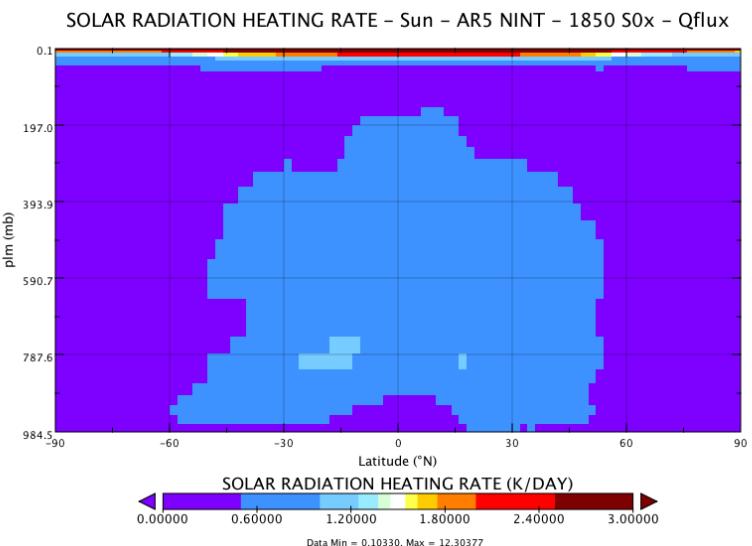


Sun

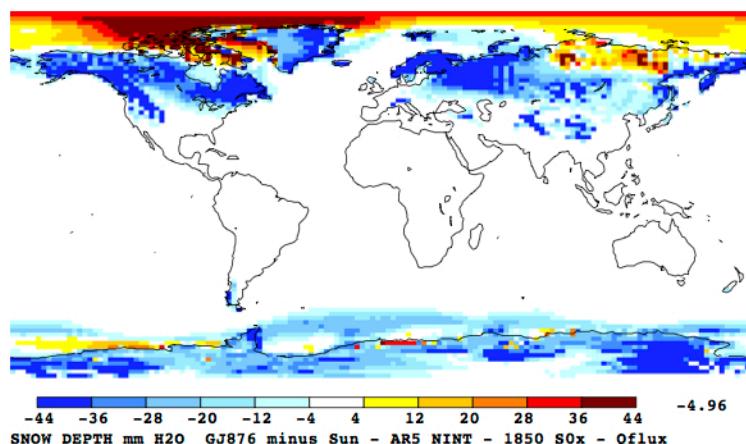
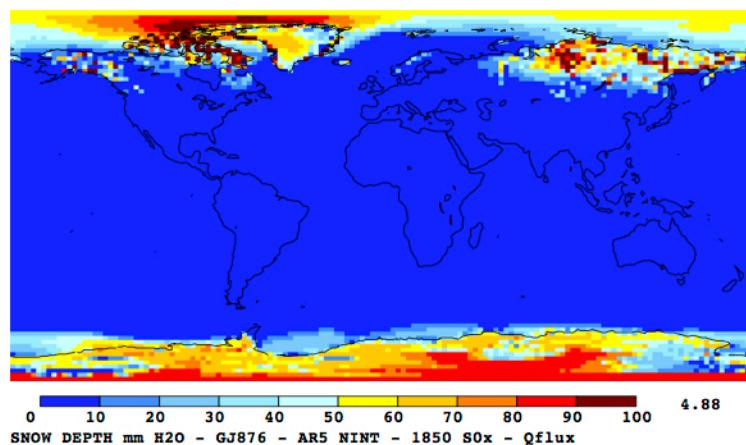
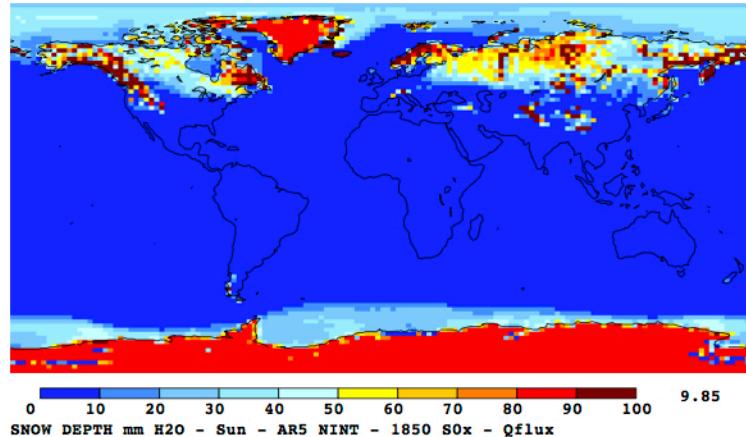
GJ876

GJ876
minus
Sun

SW Heating Rate (lat vs. height)

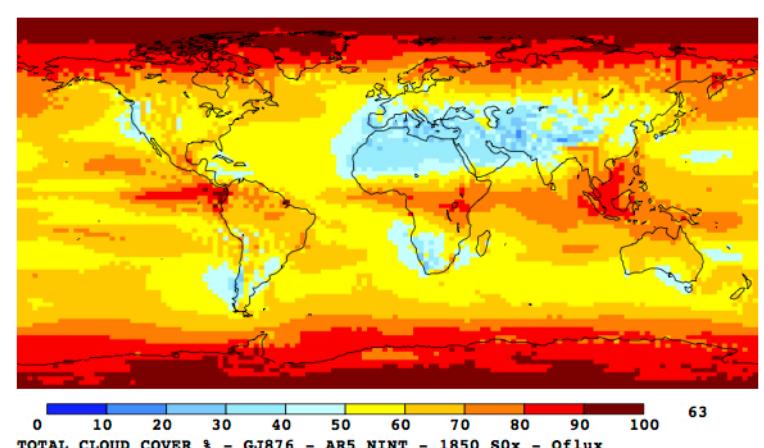
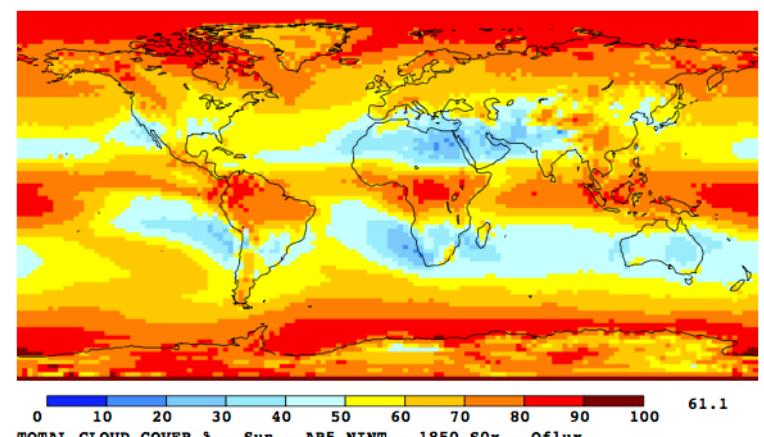


Snow depth



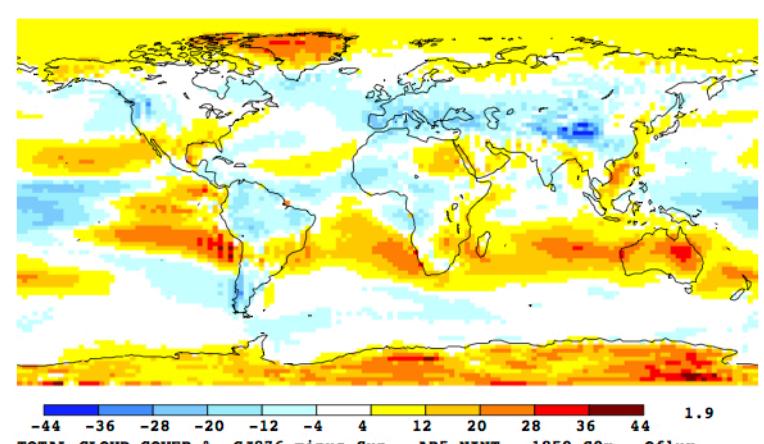
Sun

Total cloud cover %



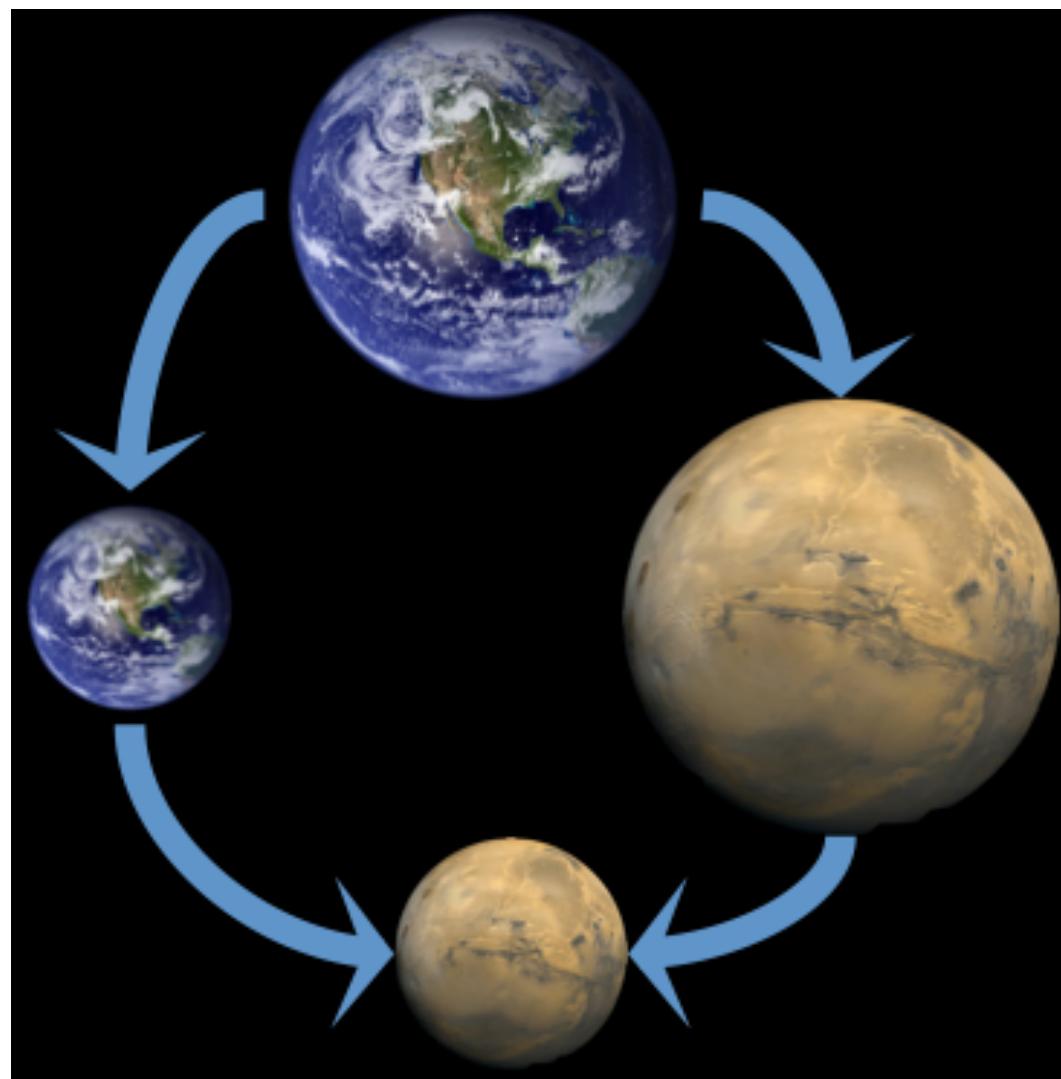
GJ876

GJ876
minus
Sun



Getting from Earth to Mars

1.) Gravity/Radius – Topography



Getting from Earth to Mars?

- 2.) Insolation (0.43) – Radiation code bounds (Max Kelley)
- 3.) Desert World – eliminate oceans, Topography (Max/Jeff)
- 4.) Atm Pressure & Constituents (CO_2 and trace H_2O no O_3)
- 5.) Orbital Parameters for Mars (Clune)
 - Longitude of Perihelion, eccentricity, obliquity, calendar
- 6.) Clouds (**Ackerman**) & CO_2 condensation (**Igor Aleinov**)

Getting from Earth to Mars?

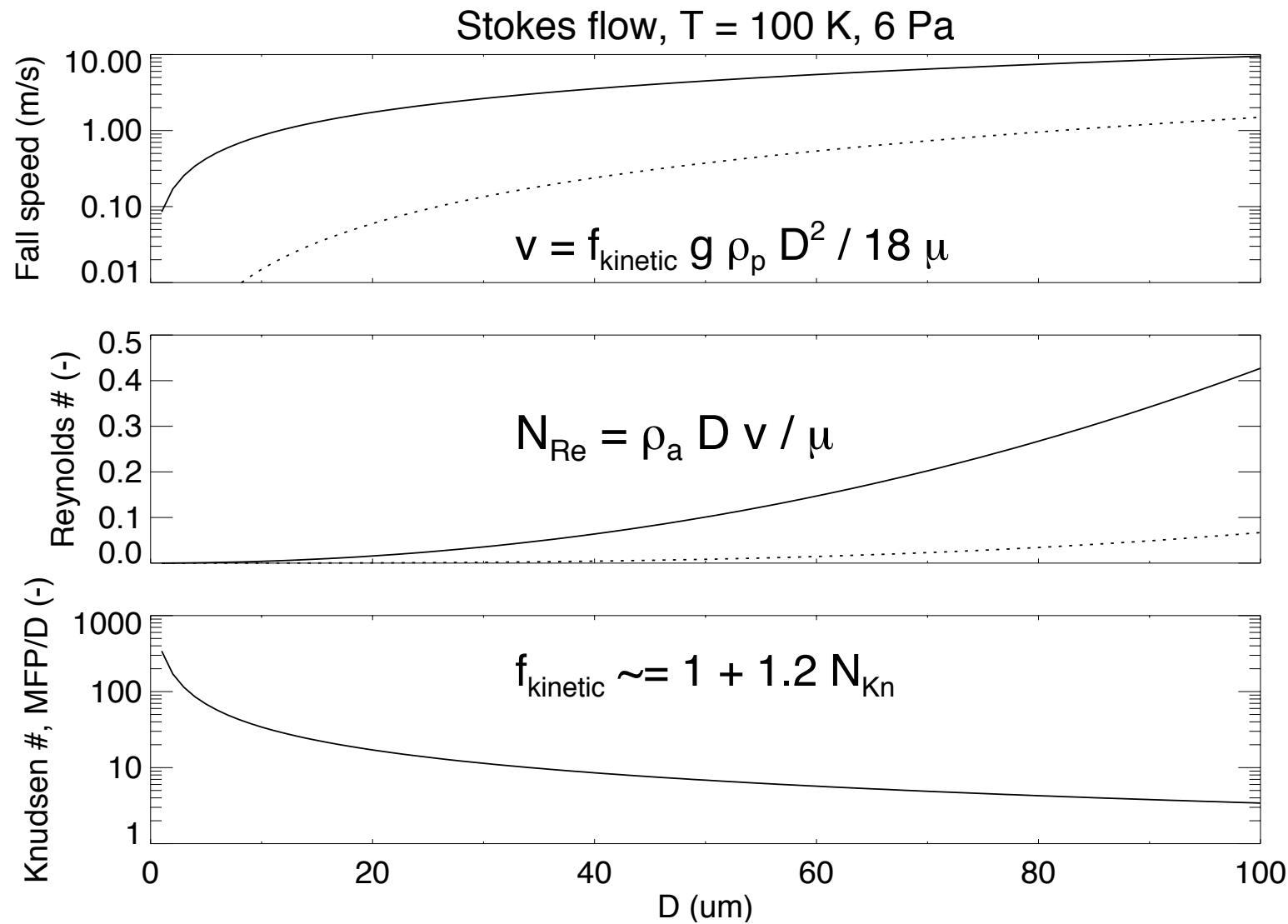
7.) Photolysis (K. Tsigaridis):

- decoupled code from current chemistry scheme
- photolysis compiles when current chemistry absent
- hence photolysis available with any new future chemistry
- attempt to removed hard coded O₂ concentrations, but realized it's probably easier to replace chemistry code

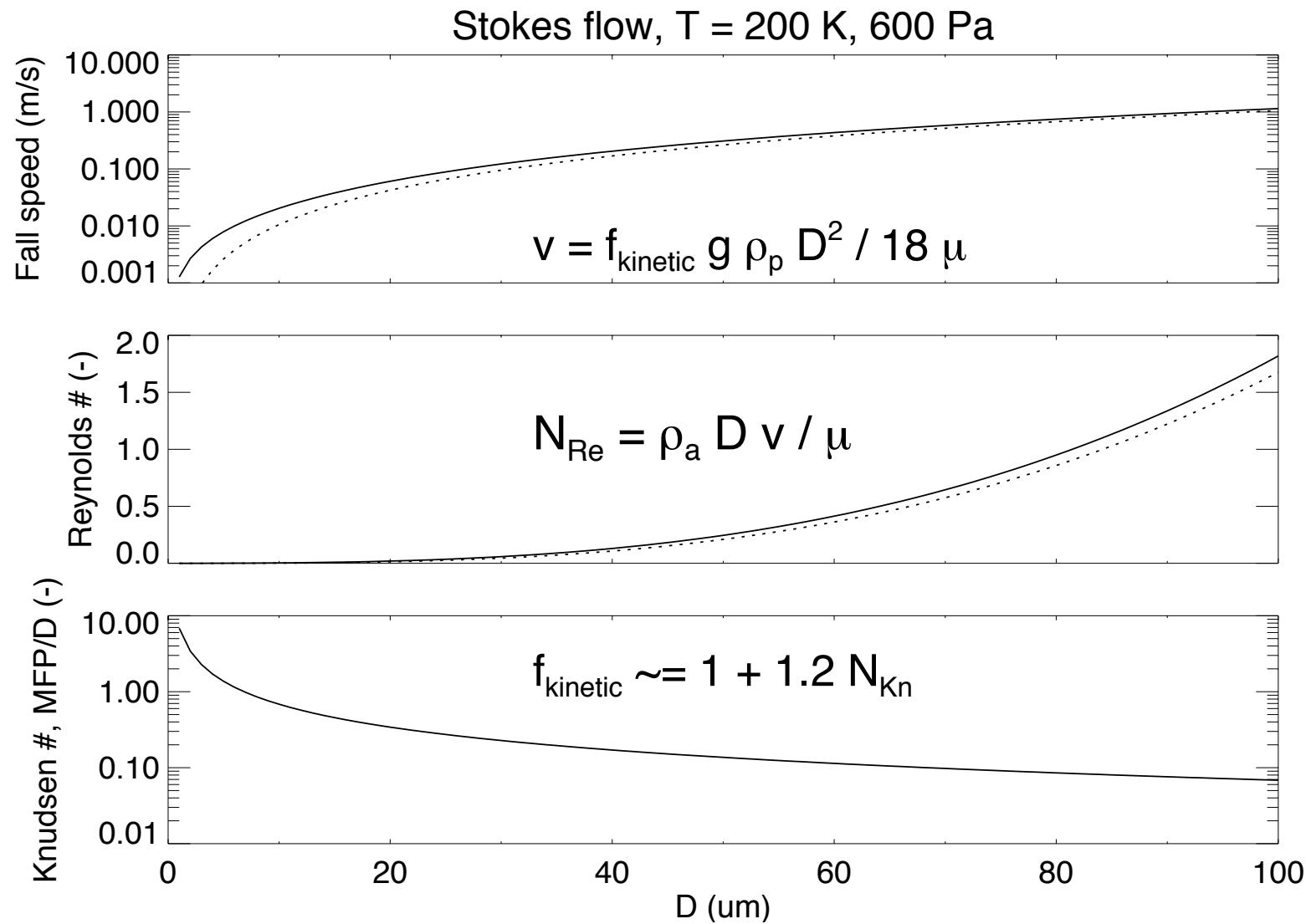
8.) Dust (Jeff Jonas)

9.) Ability to Increase/Decrease Land Ice (Polar Caps)

Ackerman: Clouds

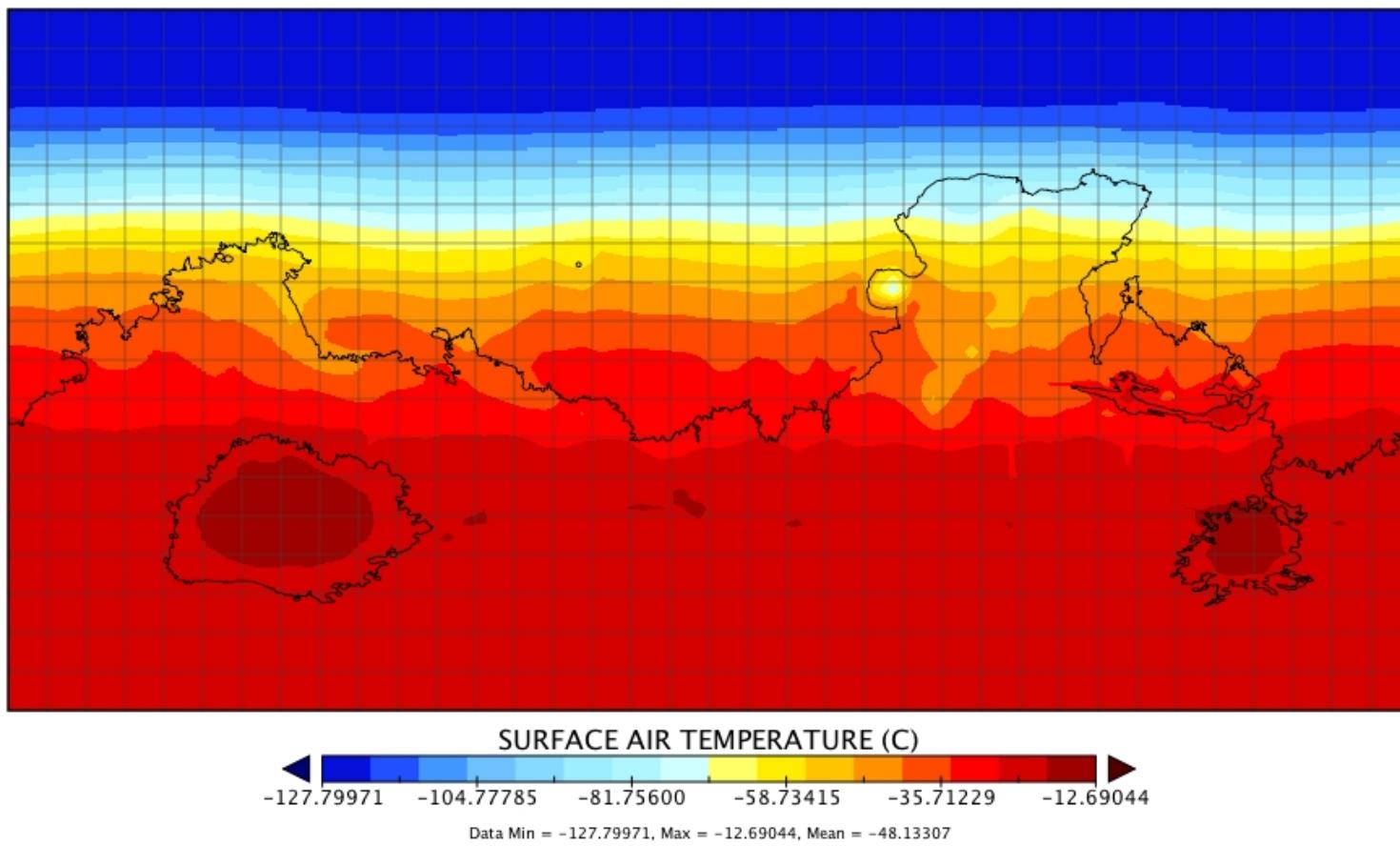


Ackerman: Clouds



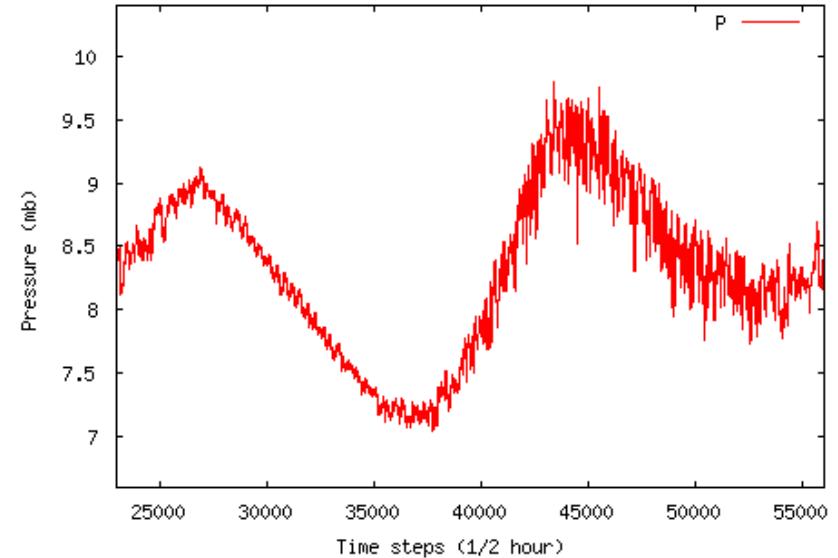
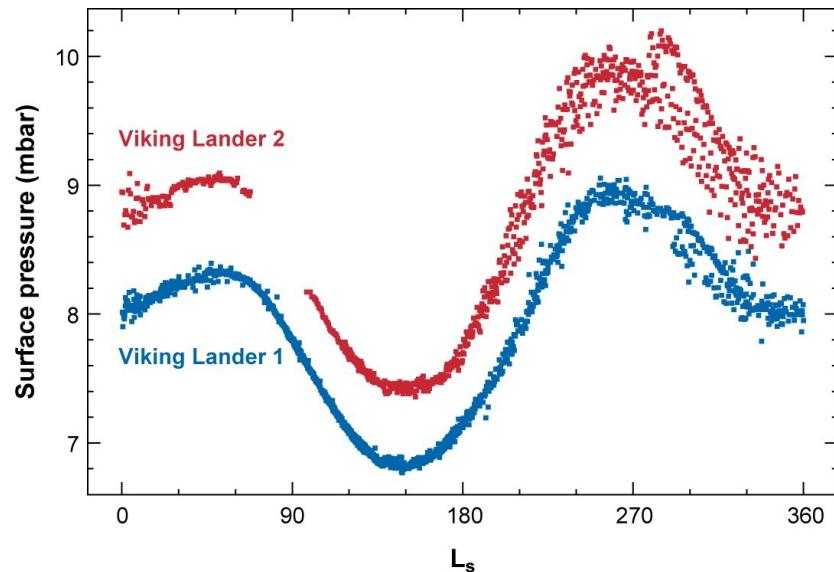
Actual Mars (-143<T_{mars}<35)

Mars (CO2X=3333) w/CO2 Cond 10 yr average DECEMBER



Aleinov: CO₂ Condensation

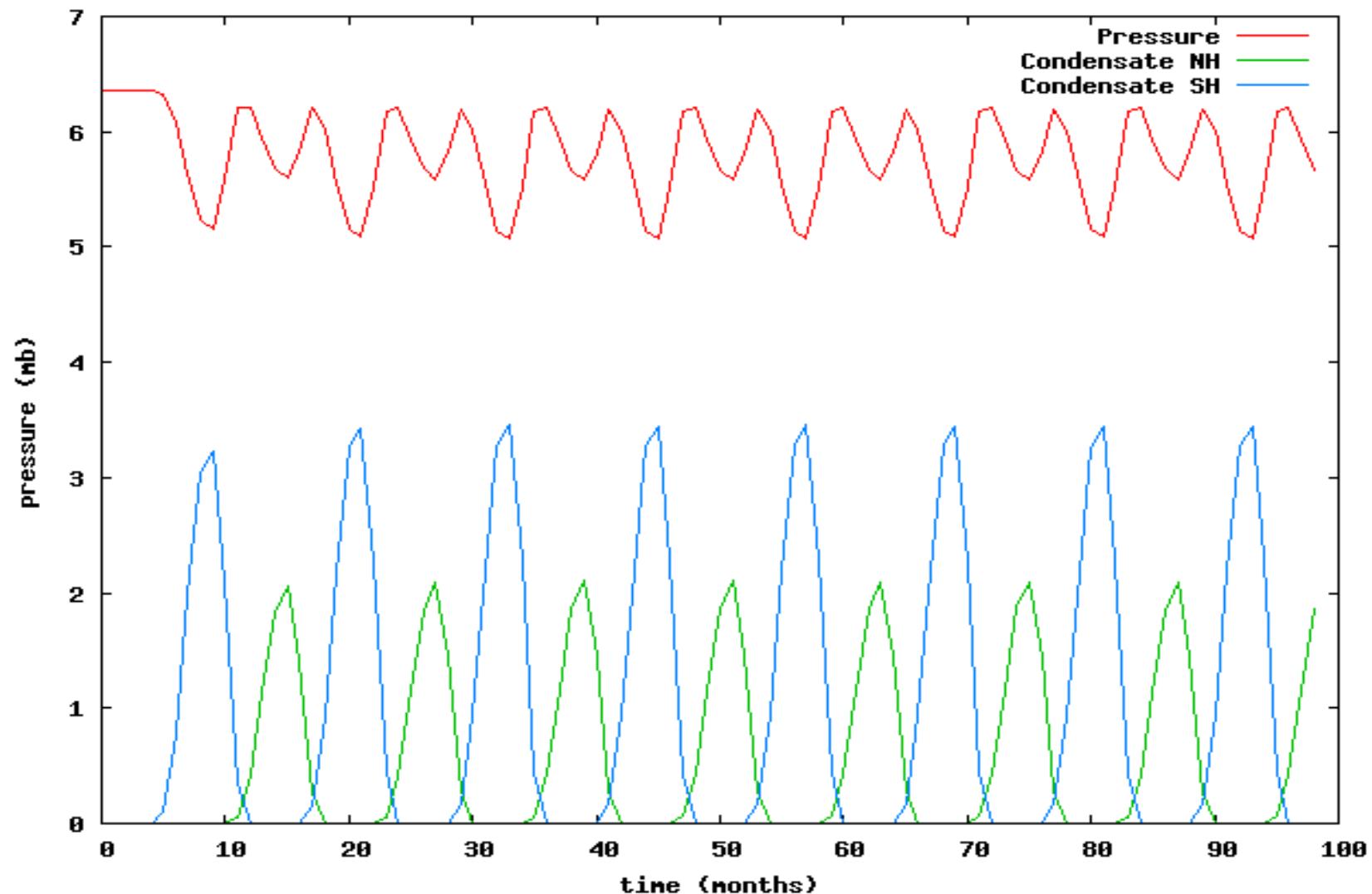
Surface pressure at Viking 2 landing site



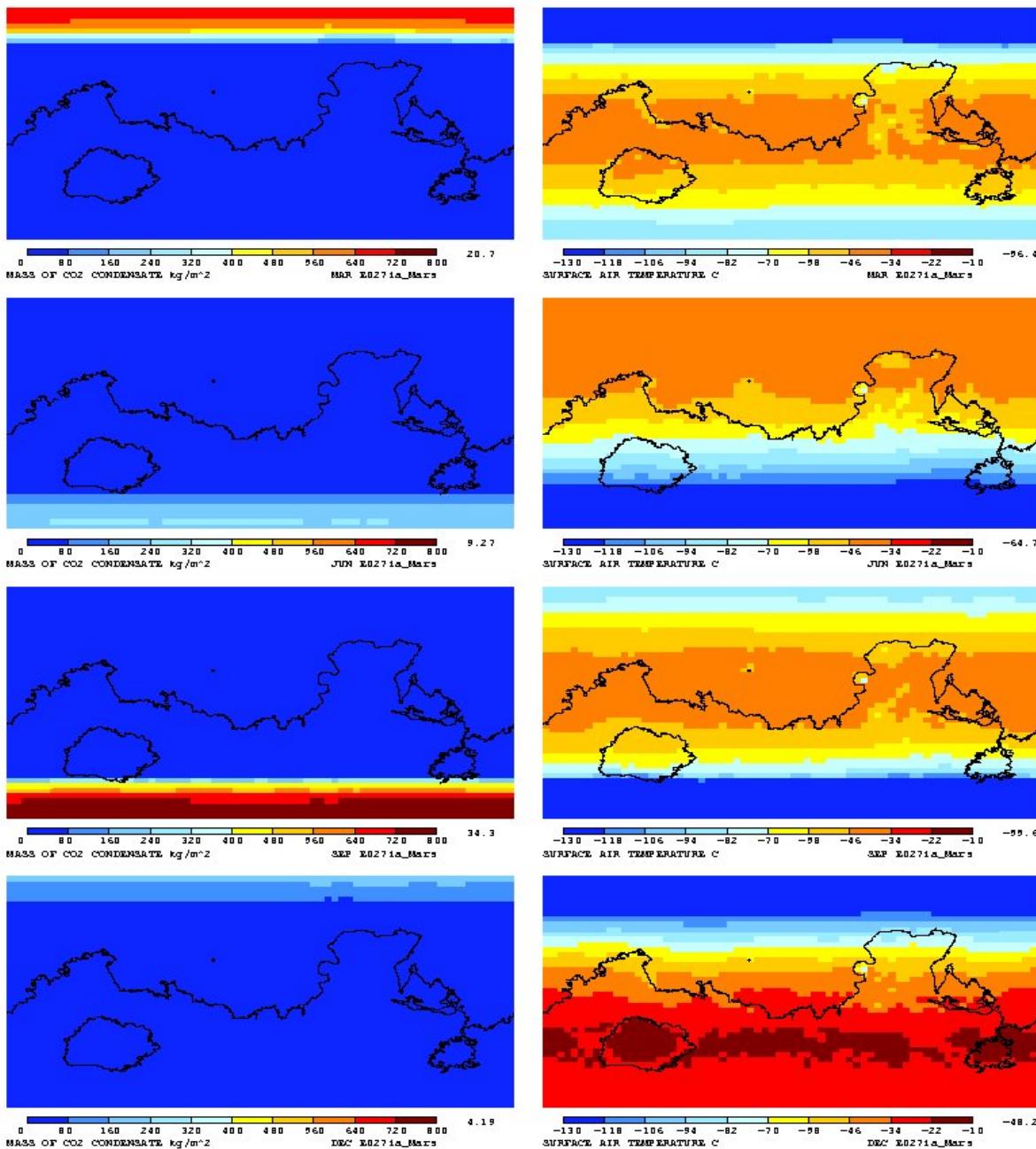
Smith MD. 2008.
Annu. Rev. Earth Planet. Sci. 36:191–219.

ModelE, Viking2 site

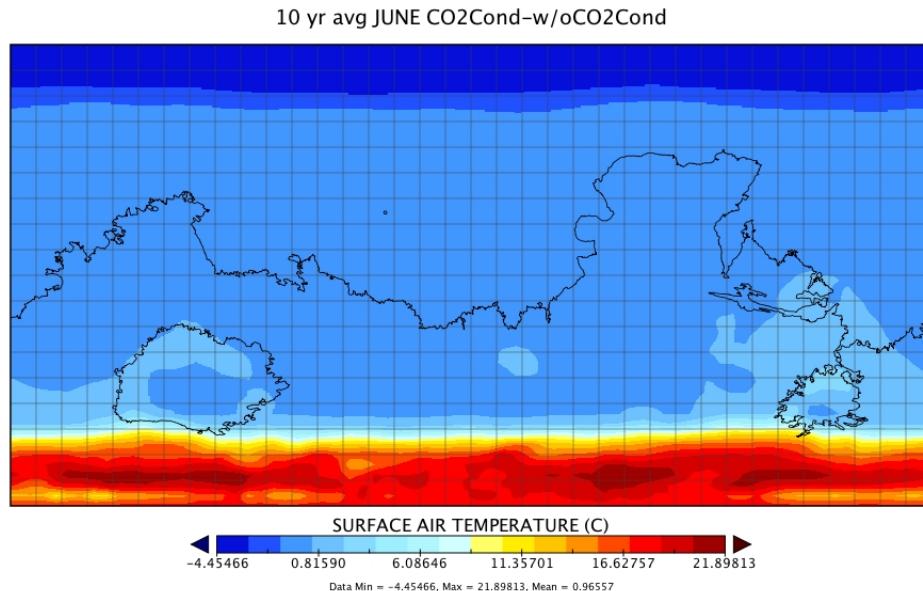
Surface pressure and CO₂ condensate



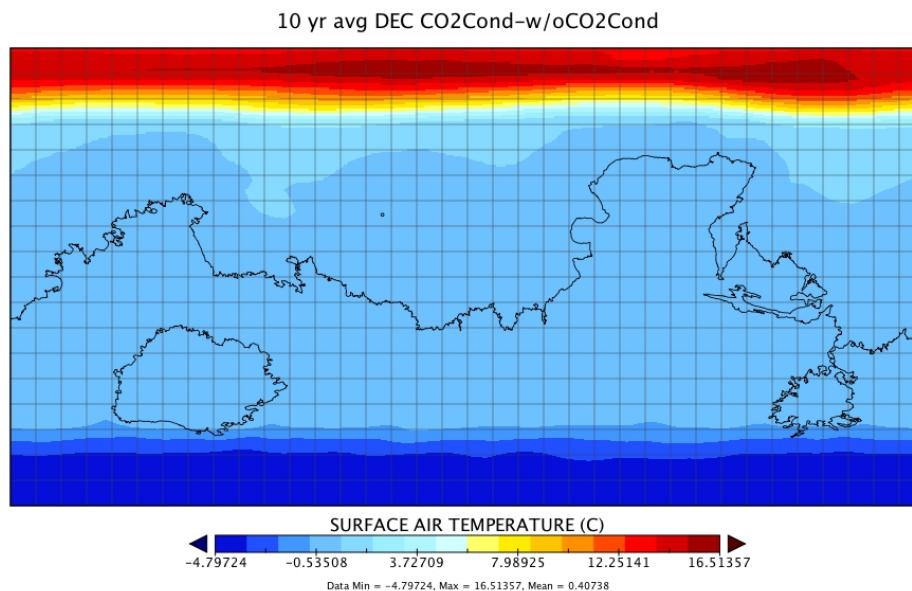
Mass of condensate and temperature



Differences CO₂ Cond – w/o Cond

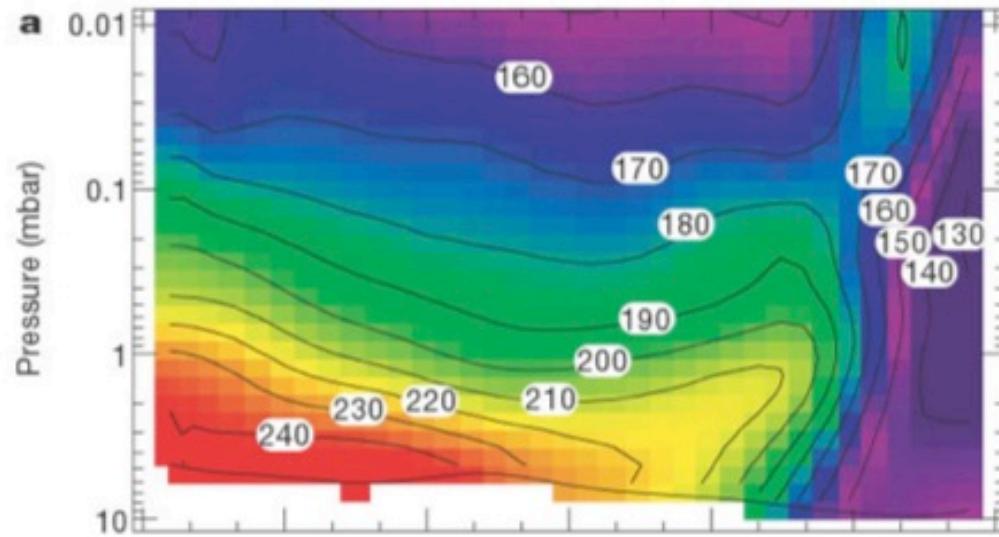


June Mean tsurf =0.96

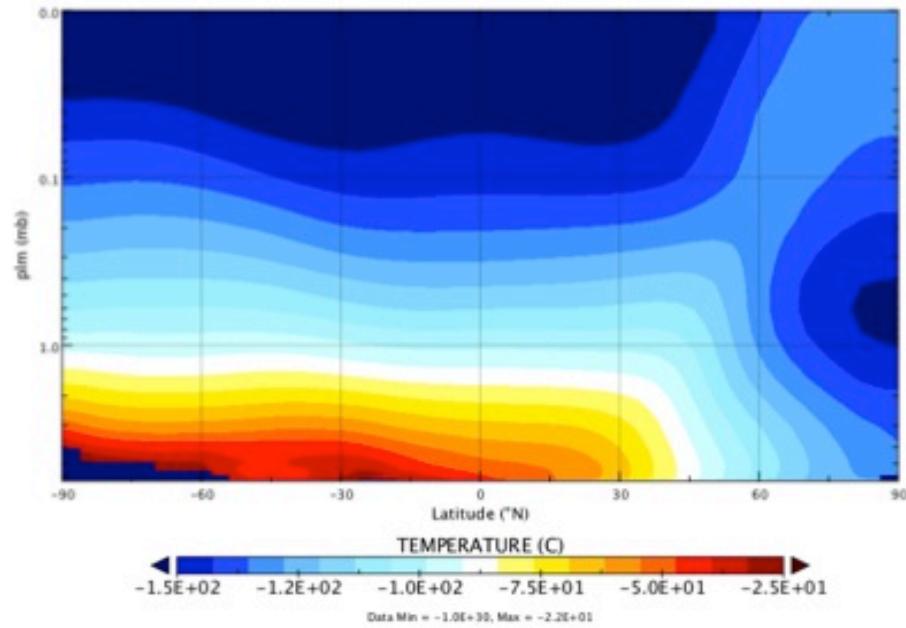


Dec Mean tsurf =0.41

Mars Zonal Mean Temp Profile



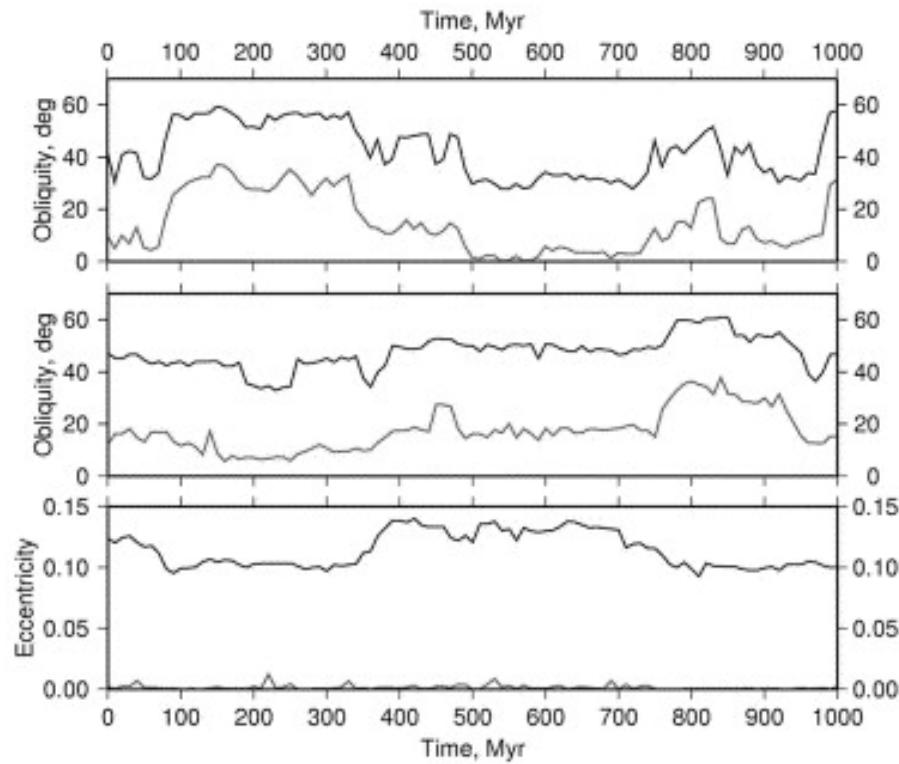
MGS Observations



GISS Mars w/CO₂ Cond

Getting from Mars to Paleo Mars?

1.) Variable orbital parameters



Time history of minimum and maximum values of the obliquity prior to the formation of Tharsis (top), subsequent to the formation of Tharsis (middle) and the orbital eccentricity (bottom) for 1 Gyr.
(Armstrong et al. 2004, Icarus 171, 255)

Getting from Mars to Paleo Mars?

- 2.) Add oceans (watershed method)
- 3.) Collisionally Induced Absorption (CO_2)
- 4.) Cloud possibilities (Kasting et al. ?)

Applicable to Faint Young Sun on Earth (FYS)?

Exploring the Inner Edge of the Habitable Zone

- 1.) Easier on the model than exploring the outer edge
- 2.) Testing model Physics at an extreme
- 3.) S0X=1 -> 1.35 successful thus far
- 4.) Turned off Aerosols, O₂, F11/12, CFCs, SO₂ and O₃
(except when S0X>=1.2 we need O₃=0.0625)
- 5.) Tested 50mb cloud formation limit at S0X=1.3, now
possible to set to zero in master branch rundeck (Yao).

Inner Edge (Qflux Ocean) 4x5x20

